In This Lecture

• Transactions
• Recovery
  • System and Media Failures
• Concurrency
  • Concurrency problems
• For more information
  • Connolly and Begg chapter 20
  • Ullman and Widom 8.6
Transactions

- A transaction is an action, or a series of actions, carried out by a single user or an application program, which reads or updates the contents of a database.
Transactions

• A transaction is a ‘logical unit of work’ on a database
  • Each transaction does something in the database
  • No part of it alone achieves anything of use or interest

• Transactions are the unit of recovery, consistency, and integrity as well

• ACID properties
  • Atomicity
  • Consistency
  • Isolation
  • Durability
Atomicty and Consistency

• Atomicity
  • Transactions are atomic – they don’t have parts (conceptually)
  • can’t be executed partially; it should not be detectable that they interleave with another transaction

• Consistency
  • Transactions take the database from one consistent state into another
  • In the middle of a transaction the database might not be consistent
Isolation and Durability

• Isolation
  • The effects of a transaction are not visible to other transactions until it has completed
  • From outside the transaction has either happened or not
  • To me this actually sounds like a consequence of atomicity...

• Durability
  • Once a transaction has completed, its changes are made permanent
  • Even if the system crashes, the effects of a transaction must remain in place

Transactions and Recovery
Example of transaction

- Transfer £50 from account A to account B
  - Read(A)
  - A = A - 50
  - Write(A)
  - Read(B)
  - B = B + 50
  - Write(B)

- Atomicity - shouldn’t take money from A without giving it to B
- Consistency - money isn’t lost or gained
- Isolation - other queries shouldn’t see A or B change until completion
- Durability - the money does not go back to A

Transactions and Recovery
The Transaction Manager

- The transaction manager enforces the ACID properties
  - It schedules the operations of transactions
  - COMMIT and ROLLBACK are used to ensure atomicity

- Locks or timestamps are used to ensure consistency and isolation for concurrent transactions (next lectures)
- A log is kept to ensure durability in the event of system failure (this lecture)
COMMIT and ROLLBACK

- COMMIT signals the successful end of a transaction
  - Any changes made by the transaction should be saved
  - These changes are now visible to other transactions

- ROLLBACK signals the unsuccessful end of a transaction
  - Any changes made by the transaction should be undone
  - It is now as if the transaction never existed
Transactions and Recovery

Recovery

- Transactions should be durable, but we cannot prevent all sorts of failures:
  - System crashes
  - Power failures
  - Disk crashes
  - User mistakes
  - Sabotage
  - Natural disasters

- Prevention is better than cure
  - Reliable OS
  - Security
  - UPS and surge protectors
  - RAID arrays

- Can’t protect against everything though
The Transaction Log

- The transaction log records the details of all transactions
  - Any changes the transaction makes to the database
  - How to undo these changes
  - When transactions complete and how

- The log is stored on disk, not in memory
  - If the system crashes it is preserved

- Write ahead log rule
  - The entry in the log must be made before COMMIT processing can complete
System Failures

- A system failure means all running transactions are affected
  - Software crashes
  - Power failures
- The physical media (disks) are not damaged

- At various times a DBMS takes a checkpoint
  - All committed transactions are written to disk
  - A record is made (on disk) of the transactions that are currently running
Types of Transactions

Transactions and Recovery
System Recovery

• Any transaction that was running at the time of failure needs to be undone and restarted
• Any transactions that committed since the last checkpoint need to be redone

• Transactions of type $T_1$ need no recovery
• Transactions of type $T_3$ or $T_5$ need to be undone and restarted
• Transactions of type $T_2$ or $T_4$ need to be redone
Transaction Recovery

UNDO and REDO: lists of transactions

UNDO = all transactions running at the last checkpoint
REDO = empty

For each entry in the log, starting at the last checkpoint
  If a BEGIN TRANSACTION entry is found for T
    Add T to UNDO
  If a COMMIT entry is found for T
    Move T from UNDO to REDO
Transaction Recovery

UNDO: T₂, T₃
REDO: Last Checkpoint
Active transactions: T₂, T₃
Transaction Recovery

**UNDO:** T₂, T₃, T₄

**REDO:**
- T₄ Begins
- Add T₄ to UNDO
UNDO: \( T_2, T_3, T_4, T_5 \)

REDO:

\( T_5 \) begins

Add \( T_5 \) to UNDO
Transaction Recovery

UNDO: T₃, T₄, T₅
REDO: T₂

T₂ Commits
Move T₂ to REDO

Transactions and Recovery
Transaction Recovery

UNDO: T₃, T₅
REDO: T₂, T₄

T₄ Commits
Move T₄ to REDO
Forwards and Backwards

- **Backwards recovery**
  - We need to undo some transactions
  - Working backwards through the log we undo any operation by a transaction on the UNDO list
  - This returns the database to a consistent state

- **Forwards recovery**
  - Some transactions need to be redone
  - Working forwards through the log we redo any operation by a transaction on the REDO list
  - This brings the database up to date
Media Failures

- System failures are not too severe
  - Only information since the last checkpoint is affected
  - This can be recovered from the transaction log

- Media failures (disk crashes etc) are more serious
  - The data stored to disk is damaged
  - The transaction log itself may be damaged
Backups

- Backups are needed to recover from media failure
  - The transaction log and entire contents of the database is written to secondary storage (often tape)
  - Time consuming, and often requires down time

- Backups frequency
  - Frequent enough that little information is lost
  - Not so frequent as to cause problems
  - Every day (night) is common

- Backup storage

Transactions and Recovery
Recovery from Media Failure

- Restore the database from the last backup
- Use the transaction log to redo any changes made since the last backup
- If the transaction log is damaged you can’t do step 2
  - Store the log on a separate physical device to the database
  - The risk of losing both is then reduced
Concurrency

• Large databases are used by many people
  • Many transactions to be run on the database
  • It is desirable to let them run at the same time as each other
  • Need to preserve isolation

• If we don’t allow for concurrency then transactions are run sequentially
  • Have a queue of transactions
  • Long transactions (e.g., backups) will make others wait for long periods

Transactions and Recovery
Concurrency Problems

• In order to run transactions concurrently we interleave their operations
• Each transaction gets a share of the computing time

• This leads to several sorts of problems
  • Lost updates
  • Uncommitted updates
  • Incorrect analysis

• All arise because isolation is broken
Lost Update

- T1 and T2 read X, both modify it, then both write it out
  - The net effect of T1 and T2 should be no change on X
  - Only T2’s change is seen, however, so the final value of X has increased by 5
Uncommitted Update

- T2 sees the change to X made by T1, but T1 is rolled back
  - The change made by T1 is undone on rollback
  - It should be as if that change never happened

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read(X)</td>
<td>Read(X)</td>
</tr>
<tr>
<td>X = X - 5</td>
<td>X = X + 5</td>
</tr>
<tr>
<td>Write(X)</td>
<td>Write(X)</td>
</tr>
<tr>
<td>ROLLBACK</td>
<td>COMMIT</td>
</tr>
</tbody>
</table>
Inconsistent analysis

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Read(X)</td>
<td>Read(X)</td>
</tr>
<tr>
<td>X = X - 5</td>
<td>Read(Y)</td>
</tr>
<tr>
<td>Write(X)</td>
<td>Sum = X+Y</td>
</tr>
<tr>
<td>Read(Y)</td>
<td></td>
</tr>
<tr>
<td>Y = Y + 5</td>
<td></td>
</tr>
<tr>
<td>Write(Y)</td>
<td></td>
</tr>
</tbody>
</table>

- T1 doesn’t change the sum of X and Y, but T2 sees a change
  - T1 consists of two parts – take 5 from X and then add 5 to Y
  - T2 sees the effect of the first, but not the second
Next Lecture

- Concurrency
  - Locks and resources
  - Deadlock

- Serialisability
  - Schedules of transactions
  - Serial & serialisable schedules

- For more information
  - Connolly and Begg chapter 20
  - Ullman and Widom 8.6